NATURAL ENVIRONMENT RESEARCH COUNCIL

Planet Earth

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Summer 2011

The coolest job on the planet?

Of muck and men • Shearwaters • Geoforensics • Biofuels • SAHFOS 80th anniversary • Penguins

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Planet Earth
Summer 2011

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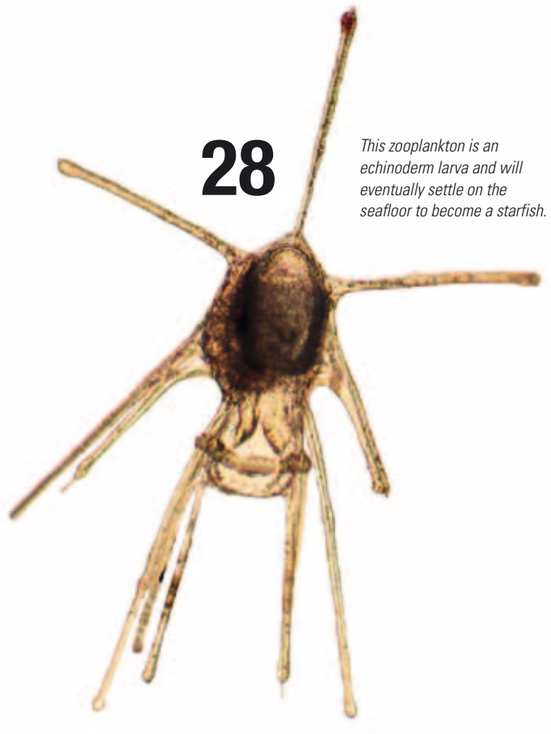

This zooplankton is an echinoderm larva and will eventually settle on the seafloor to become a starfish.

NERC scientists: we want to hear from you

Planet Earth is always looking for interesting NERC-funded science for articles and news stories. If you want to see your research in the magazine, contact the editors to discuss. Please don't send in unsolicited articles as we can't promise to publish them. We look forward to hearing from you.

Planet Earth is the quarterly magazine of the Natural Environment Research Council. It aims to interest a broad readership in the work of NERC. It describes new research programmes, work in progress and completed projects funded by NERC or carried out by NERC staff. Some of this work may not yet have been peer-reviewed. The views expressed in the articles are those of the authors and not necessarily those of NERC unless explicitly stated. Let us know what you think about *Planet Earth*. Contact the editors for details.

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Front cover: British Antarctic Survey diver under the ice.

Change is in the air

Alan Thorpe *Chief Executive, NERC*

After six years at NERC I am moving on to become Director-General of the European Centre for Medium-Range Weather Forecasts.

Looking back, I can see some clear trends in the development of environmental science in that time. Of course scientific progress is mostly incremental, but NERC's area of science is advancing at a rapid pace and our understanding of environmental change has progressed dramatically.

The challenges of understanding our planet and the life it supports do not respect the boundaries between scientific fields, and over the last six years we have started to create projects and partnerships that draw on the expertise of many different disciplines to reflect this.

This approach is sometimes called Earth-system science. It is now widely accepted that to address the environmental challenges we face, we need holistic solutions. The natural sciences themselves must integrate, as well as work with other disciplines like social science, engineering and economics. These approaches will ensure that research programmes are designed to address practical problems, and that the results make change happen on the ground without the need for a lengthy translation of research into policy. Living with Environmental Change is driving this approach, and I am proud that NERC is making such an important contribution to this ground-breaking partnership.

There have been hugely influential developments in the way we observe the environment, too, both on the ground and from space. I well remember how doubtful people were about the value of satellite measurements when I was a young post-doctoral researcher. How times have changed! Satellites now provide valuable insights into the Earth system that can't be made by any other means.

A major result of our combined Earth and space observations has been a huge step forward in our understanding of the circulation of the Atlantic Ocean – the Meridional Overturning Circulation (MOC). A few years ago we didn't even know if it was possible to measure the MOC; now we can see the strength and variability of this vital system in high resolution.

Combining these new observations with models has produced a growing appreciation of the importance of modelling for predicting how our environment is likely to respond to change; and integrating theory and measurement is transforming this prediction system. Research programmes like RAPID Climate Change have broken down the barriers between modellers and observers, to the benefit of both groups.

This integration has revealed numerous remarkable aspects of climate change – for example, the contrasting trends in polar sea ice, with a rapid decrease in extent in the Arctic and a small but significant increase around the Antarctic. The ozone hole has played a large part in this increase, essentially by shielding high southern latitudes from the influences of increasing greenhouse gases. But as the ozone hole 'heals', this shielding effect will disappear, and the resulting reduction in ice will add to sea-level rise.

This knowledge matters, and how we communicate it is equally important. As scientists we know now, more than ever, that we have a responsibility to engage the public with our research. This is an opportunity as well as a duty; environmental science is of fundamental interest to society and this interest can greatly enhance our work if we can be as good at listening as we are at research.

The strength of public interest is evident in the growth of 'citizen science', in which non-scientists contribute to a research project by gathering data or helping analyse results. The new Red List highlighting the health of Britain's butterflies relied heavily on information recorded by the public, and last year researchers at Bristol University enrolled hundreds of schoolchildren to help them study the damage being caused to horse chestnuts by the leaf miner moth; the project will run again in 2011.

We have also seen what happens when science consults public opinion too late; perhaps the widespread rejection of genetically modified organisms could have been avoided if researchers and policy-makers had addressed public concerns at an early stage. Now, as the world considers whether geoengineering could offer viable solutions to climate change, NERC is making sure that public opinion has a say in research priorities. Last year we hosted a series of public debates to discover what people understand by geoengineering, what approaches they find acceptable and, importantly, what practical questions they have that scientists might not even have considered.

So, as I move on, environmental science is ready for its next step forward. Integrating the environmental sciences with other disciplines, combining observational and modelling capabilities, and expanding national endeavours into global ones will bring networks of researchers together to address the urgent questions society faces. Though I am leaving NERC I will be following these developments closely.

NEWS

A word in your shell-like

A much wider range of baby shellfish can hear and react to underwater noise than scientists previously thought. These tiny crustaceans use noise to avoid predators that lie in wait around busy coral reefs, researchers have found.

Even though the creatures are as small as a flea, they clearly have some sort of hearing system that lets them pick up the pops, grunts and gurgles made by fish, shrimps, urchins and other coral reef dwellers.

Scientists have only relatively recently found that tiny fish larvae can also hear, and use the noise of the reef to figure out where to set up home. Now this is the first time scientists have found evidence that many crustaceans hear too, but in this research, the scientists found that noise deters them away from reefs. The researchers don't yet know how they manage this, but suspect they may have the same simple hearing system that fish have.

Fish have both hair-like receptors that detect the movement of water particles and membrane receptors that pick up oscillating particles.

Many crustacean larvae need to avoid coral reefs – they come out to feed at night, when predators are on the prowl. Their natural enemies include soldierfish, squirrelfish, and millions of corals and filter feeders attached to the reef.

The coral reef is like a 'wall of mouths' to these animals, so when they hear noise, they avoid it.

Steve Simpson, University of Bristol

'The coral reef is like a "wall of mouths" to these animals, so when they hear noise, they avoid it,' says Dr Steve Simpson, a marine biologist at the University of Bristol, and lead author of the research, published in *PLoS ONE*.

This means that underwater noise from human activities like dynamite fishing, drilling and boats could affect all sorts of marine creatures much more than previously suspected.

'These crustaceans are major groups in tropical waters and underpin many food webs. Anthropogenic noise could lead to maladaptive behaviour and leave them swimming towards sounds they should be moving away from,' explains Simpson.

Waste not want not

Organic refuse from households and industry can help turn polluted soils back into rich and varied habitats. But a shift in public and government attitudes is needed before this can happen, scientists say.

A recent paper published in *Elements* describes how researchers managed to restore heavily contaminated sites by applying specially designed mixes of organic waste, which would otherwise often end up in landfill sites.

'Remediating land with waste has gained more interest recently, but the science is still in its early stages,' says Professor Davey Jones of Bangor University, who led the research. 'What's unusual here is that we managed to end up with high-biodiversity grassland, whereas in the past people have often been content to remove the most harmful pollution and end up with a site covered in something like football turf.'

Jones and his colleagues worked on two sites in north Wales. The first was an area of slate-mining waste and the second an old industrial site contaminated with heavy metals and organic chemicals.

The team added different compost mixes to the two areas and after 18 months diverse grassland had established on the sites.

Each site needs a particular blend of waste materials, with different plants seeded on top.

Jones says the technique has great potential, but the major hurdle is acceptance, both from the general public and from regulators and policy-makers. Many people dislike the idea of spreading sewage and other waste on the land, even if it's not dangerous.

The researchers say they still need to understand how the process works over the long term and which kinds of waste work best in each situation, as well as how far it's worth transporting different types of organic material before the financial costs and carbon footprint start to outweigh the benefits.

Mona Makela/Shutterstock

Keeping Europe's lights on when space weather strikes

NASA/Goddard Space Flight Centre

We take reliable lighting and heating for granted. But imagine if we had no electricity for days on end – what would happen to our telephone system, our schools, hospitals and food distribution networks? How long could you last without your fridge, or with no fresh food on supermarket shelves?

In the last few decades scientists have learned that our electrical supply is at risk from space weather. Solar storms, flung into space by the Sun, can play havoc with the Earth's magnetic field, causing large and rapid magnetic variations that induce damaging electrical currents in power systems across the world. In 1989 the Hydro-Quebec grid failed when protective measures were tripped by space weather, and the same storm caused transformer damage to Britain's grid.

Now a consortium of European scientists including researchers from the British Geological Survey (BGS) have come together to study this risk, in the EU-funded programme European Risk from Geomagnetically Induced Currents (EURISGIC).

This is the most ambitious programme of its kind. No one knows how the inter-connected European grid responds to space weather impacts. National networks have been studied, but no one has tried to put all the national pieces together before.

EURISGIC will develop mathematical models of how the European system responds to space weather. The programme will find the worst cases in the archives, identify 'hot spots' in the system, and develop monitoring and forecasting capabilities. An advisory group of power-industry experts will help develop new strategies for the operation and adaptation of Europe's power networks in the light of the findings.

EURISGIC kicked-off in March 2011 and will run for three years. Dr Alan Thomson, head of Geomagnetism at BGS, is leading Britain's input.

'The project represents a fantastic opportunity to really push space weather and geomagnetism science and to make a difference in everyday life,' he explains.

EURISGIC comes at an appropriate time. Solar activity has started to pick up again after an extended period in the doldrums. Peak activity is expected around 2013, and the threat from solar storms will then be at its greatest.

For further information contact Alan Thomson – awpt@bgs.ac.uk

NEWS

Low-carbon future? You have to play the game

How would you make the UK's energy system low carbon, secure and affordable if you were in charge?

A new game at the Science Museum London's recently opened *atmosphere* gallery gives you a chance to have a go. Researchers from the UK Energy Research Centre (UKERC) helped create Carbon Minister, a game that gives you 40 years to transform a fictional country's energy system.

At each turn you choose how to invest in new technologies, research and development, energy-efficiency measures, and retiring dirty old power plants. But the budget is finite, so you have to think ahead if you're going to meet the stiff carbon targets without bankrupting the country or letting the lights go out.

UKERC provided information on cost, availability and carbon emissions for the energy technologies that underpin the game, and also advised on the narrative.

Dr Jeff Hardy, UKERC knowledge exchange manager, led the UKERC input.

'The *atmosphere* gallery brings the science of the Earth's changing climate to the public at a level of detail normally reserved for scientists and policy-makers. It's vital that we help people understand the challenges and choices ahead as we move to a low-carbon society. The game helps you understand the difficult choices we face – it's far from easy and despite having designed the rules I still failed first time I played it!'

In *atmosphere* you can discover some key instruments used by scientists, learn about the latest climate news, and dig deeper into the story of our changing climate. The gallery has its own land, oceans, ice and atmosphere, and Carbon Minister is just one of five interactive games that allow you to see your actions played out before your eyes.

During 2011 National Science and Engineering Week UKERC will also be putting groups of university students through their low-carbon paces in a game called Energy Islands. Students are in charge of three islands. Each group has to decide how to decarbonise their own island and negotiate with their neighbours for the technology and resources to do it.

UKERC is the hub of UK energy research and the gateway between the UK and the international energy research communities.

www.ukerc.ac.uk

Humans reach rock bottom


Chris/istockphoto.com

Human activities are affecting large areas of the deep seabed, according to a recent study – and trawling does the most widespread damage.

More regulation is needed before the ocean floor suffers even more, the scientists say. Better data on human activities – where they're taking place and how much harm they are causing – is also vital to let us manage the whole ecosystem.

'Human activities are expanding into the deep sea at an unprecedented rate, and these ecosystems are under more pressure than ever before with new activities like carbon capture and storage, mining for minerals and deeper drilling for oil and gas,' says Angela Benn of the National Oceanography Centre, who led the study.

Benn analysed and combined the available information on the location of different human activities during 2005 on the deep seafloor in the OSPAR (Oslo Paris Commission) area of the northeast Atlantic. The area is heavily exploited and contains important fisheries and oil and gas fields.

Until recently, many countries just dumped unwanted material into the abyss and forgot about it. That's left an alarming legacy of contamination, ranging from scuttled ships, old ordnance, chemical weaponry and even radioactive waste.

But the study, published in *PLoS ONE*, makes it clear that deep-sea trawling – a fishing method in which boats drag nets across the seabed to catch bottom-dwelling prey – is currently the biggest source of harm to the deep ocean floor. Trawlers plough up and disrupt coral reefs and other sensitive habitats, and they could affect as much as 37,160km^2 of seabed.

This is ten times greater than the area affected by all the other activities in the study put together. In some areas of the northeast Atlantic, it would mean most sections of seabed get trawled at least once a year.

Benn says this study is a step forward, but that much more information is needed if appropriate regulations are to be introduced so these deep-sea ecosystems can be managed for the long term.

'Traditionally human activities in the marine environment have only been managed on an industry-by-industry basis. New approaches are now turning towards managing whole ecosystems and multiple impacts from different industries. From the point of view of fisheries, the aim has been to preserve individual fish stocks,' she explains. 'It's only recently that regulations are being developed to protect vulnerable marine ecosystems taken as bycatch in trawls.'

Humans not always to blame for coral reef decline

The decline of coral reefs over the last few decades is often squarely blamed on human activity. But a recent study suggests the picture is a little more complex.

Researchers have found that some reefs stop growing simply because they've reached the end of their natural life cycle.

The UK and Australian researchers found that some parts of Australia's Great Barrier Reef stopped growing between 4,000 and 5,000 years ago without any kind of human influence. In other places new reefs have established themselves only in the last 1,000 to 2,000 years.

'There's an assumption that degraded reef states are a function of environmental stress, linked to anthropogenic activity,' says Professor Chris Perry, an expert in coral reefs at Manchester Metropolitan University, who led the latest study, published in *Global Change Biology*.

'Whilst this is often the case, the picture is not as simple as that. Some degradation is natural and not the result of anthropogenic stress. It may simply be that a reef has gone through its natural evolutionary life cycle and then shut down.'

They might look a bit worse for wear, but this is normal; you'd expect them to look like that.

Professor Chris Perry, Manchester Metropolitan University

'Some of these reefs clearly have degraded surfaces and patchy veneers of living coral,' explains Perry. 'They might look a bit worse for wear, but this is normal; you'd expect them to look like that.'

In many areas of the world, reef degradation is clearly down to human activities. In the Caribbean reef decline since the mid-1970s is almost certainly down to pollution and overfishing.

But this latest study reveals that, in some cases, it's normal for reefs to decline.

The team's findings mean that, 'conservationists should start to include considerations of the evolutionary state of a reef and its age, as well as focusing efforts on younger and actively growing reefs that can harbour a wider range of habitat types,' says Perry.

Do you think you're sexy?

Most of us check the mirror at least once before we step out of the house, and we know instantly if we pass muster or if we're having a bad hair day. But how do animals know how attractive they are? Nick Royle and Tom Pike decided to find out.

Nick Royle

What do we mean when we talk about attractiveness in animals? An 'attractive' individual is one that can arouse interest in a potential mate, so in general the most attractive individuals are the most successful at reproducing. There has been lots of research in behavioural and evolutionary ecology, looking at variation in attractiveness and reproductive success, but very little is known about how animals actually work out how attractive they are to others.

Why is this important? It's interesting from a biological point of view, because individuals can use this information to modify the 'decisions' they make during reproduction. For example, in species where males invest their time and energy in parental care, knowing their own attractiveness may affect how much effort males put into finding a new mate relative to the effort they put into raising their existing offspring: more attractive males are expected to put more effort into mating than parental care. But do males know how attractive they are and, if so, how do they find out?

For us humans these questions are also intrinsically fascinating. Whole industries are founded on making ourselves more attractive – cosmetics, perfume, fashion – and it's the main focus of countless magazines and newspapers. Attractiveness is a constant human preoccupation, and for good reason. Studies on humans have shown that couples that have similar levels of self-perceived and partner-perceived attractiveness have more successful marriages, for example. So there are potential benefits to having an accurate perception of your own attractiveness compared to others.

Our brains are sufficiently sophisticated for us to look in a mirror and compare our own image with that of other humans in our mind's eye. But how do we know how other people would rate our attractiveness against others'? One way of finding out is through social feedback. If others are keen to spend time with you this can provide a 'behavioural mirror' that reflects how attractive you are.

Attractiveness in zebra finches is mainly a social construct.

There is evidence that some other animals adjust their courtship behaviour in response to such social feedback, but we don't know whether animals can use feedback to gain information about their own attractiveness.

To find out, we did an experiment on zebra finches in captivity to test whether social feedback from females can provide accurate information to males about their attractiveness. Female zebra finches have been shown to prefer males with brighter red beaks, and this general preference for red extends to the addition of coloured leg rings – red leg rings make males more attractive to females. In contrast, green makes males deeply unattractive. We took advantage of this quirk of female zebra finch perception, to manipulate the attractiveness of male finches independent of their actual 'quality'.

Am I hot or not?

We gathered a group of females that showed clear, unambiguous preferences for males wearing red leg rings. We then showed male birds to them under four sets of experimental conditions. First, we gave the males a red leg ring, and showed them to females on the other side of a transparent partition. This allowed the birds to see each other, so the male could see the female's response to him – her social feedback. Then we changed the partition, this time putting mirrored film on it so the male could see the female but she couldn't see him; in this set-up the males didn't receive any social feedback at all. Then we changed the male's red leg ring for a green one, and ran the experiment again with both kinds of partition.

We measured the females' interest in each male by how long they spent on the perch closest to the partition, as this has previously been shown to be a good indicator of mating preference in zebra finches.

By doing this we could make sure the actual quality of the male stayed constant while we varied the factors we were interested in: social feedback and attractiveness.

When the males and females could see each other, they gave each other more attention when males were wearing their attractive red leg ring – the female gave positive feedback and the male responded by courting her more. When the males wore green leg rings they got less positive feedback and spent less time courting. But when the females didn't respond to the males (because they couldn't see them) the amount of time the males spend courting wasn't related to which ring he was wearing – in other words his behaviour wasn't related to how attractive he thought he was.

This shows that males behave differently according to how attractive females think they are: females provide a behavioural 'mirror' that reflects male attractiveness. Males effectively find out about their own attractiveness from the females' behaviour, and this is independent of their quality as a potential mate. So it looks like attractiveness in zebra finches is mainly a social construct.

It's a neat result, but we are still not sure whether males are simply learning what responses are effective in courting particular females, or whether they somehow remember the information for use in future social interactions. Other research on social feedback among male zebra finches suggests that repeated behavioural interactions can lead to long-term changes in social status. So it seems likely that repeated behavioural interactions with females could lead to long-term changes in males' perceptions of their own attractiveness too. If so, this opens the door for future studies looking at whether males can use what they learn about their attractiveness to 'decide' how much effort to put into mating and parental care to maximise their success. For now, though, the answer to the question of how male zebra finches know how attractive they are can be broadly summarised as 'females tell them so'. ■

University of Exeter

Nick Royle in with the finches.

FURTHER INFORMATION

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Of muck and men

Tracing the spread of agriculture into Europe so many thousands of years after it happened is among the biggest challenges facing archaeologists. But the chemical signature of the manure early farmers spread on their land remains to this day. Amy Bogaard describes how her team found it.

Sharon Kingston/shutterstock.images

Michael Charles

Ian Cartwright

6000-year-old emmer wheat grain from Hambledon Hill, Dorset.

Amy Styring sampling crops at Rothamsted.

As any gardener knows, animal manure does a brilliant job of keeping soils rich in nutrients and easy to work. Though chemical fertilizers are now widely used, manuring still plays a critical role in food production in many parts of the world today. But was it always so important?

The Crop Isotope Project is the first attempt to systematically assess the importance of manuring in early farming communities, dating back thousands of years – and the results have been, well, ground-breaking.

Archaeologists know where and when the 'ingredients' of European farming emerged – around 10,500 years ago in the Middle East's Fertile Crescent – and we have a good grasp of how agriculture then spread into Europe. But what was early farming like? How were crops grown and animals raised? This kind of understanding is crucial for explaining how farming emerged and became established, as well as its long-term consequences.

In the Middle East, growing crops and herding animals emerged at around the same time. Furthermore, the early suite of crops and livestock (wheat and barley, pulses and flax, together with sheep, goats, pigs and cattle) went on to spread together across Europe. This combined crop-and-livestock 'package' hints at some sort of mixed farming.

The spread of muck-spreading

Looking at how modern small-scale farmers do things shows that cultivation and herding can be mutually beneficial: crops supplement the animal diet, for example, while livestock provide manure, disturb the soil and regulate crop growth. Importantly, manure has a 'slow-release' effect on soils and can be beneficial for years or even decades after application; it implies long-term commitment to cultivated areas.

This kind of long-term investment is at odds with the idea that early European farmers were slash-and-burn cultivators. The analogy with this form of farming, best known today in tropical latitudes, is problematic at best, but it lingers in the archaeological literature and popular imagination. If, instead, early farmers maintained arable land through manuring and other intensive practices, the implications for our understanding of their daily life, material culture and monuments are radical.

The image of early farmers carefully tending long-established gardens and fields brings into focus a world-view that gave rise both to spectacular statements of permanence and ancestral rights – such as British and Irish megalithic tombs – but also to brutal conflict. This is reflected, for example, in the 'mass grave' of an early farming community at Talheim in Germany, killed by assailants wielding stone axes like those used to clear farmland.

To assess the relevance and extent of manuring among early farmers, we needed to learn to identify it archaeologically. Agricultural soils are rarely preserved, so the primary evidence for ancient cultivation comes from crop remains – grains and inedible plant parts ('chaff') preserved mostly through charring, which renders the material biologically inert but preserves its shape.

Food science, a discipline far removed from archaeology, provided the key clue: an approach used to authenticate organic produce! Previous research showed that mineral fertilizer and farmyard manure have different effects on which forms of nitrogen get incorporated into the soil and taken up by crops.

Nitrogen comes in different forms, called 'isotopes'. Mineral nitrogen is rich in the lighter stable isotope (^{14}N), whereas farmyard manure has more of the heavier form (^{15}N). Food scientists use this contrast to identify fertilizers applied to vegetables, to ensure that only 'organic' manures were used on produce that's labelled organic.

We focused on seed crops grown by farmers of the Neolithic and the Bronze Age periods – and on how manuring affected their isotope ratios. To assess these relationships, we collected modern crop material from experimental stations across Europe, including Rothamsted in Hertfordshire, set up our own experiments – at Sutton Bonington near Nottingham and in Syria, near Aleppo – and visited regions where crops are still grown in traditional ways, including Asturias in Spain, Transylvania in Romania and Evvia in Greece.

Grains of truth

Our results left no doubt. Intensive manuring has a dramatic effect on nitrogen isotope signatures in both grain and chaff of wheat and barley; moderate manuring has a correspondingly modest effect. This means we can tell how much manure was applied, if any, from nitrogen isotopes in cereals. Pulses like peas and lentils work differently: they fix nitrogen from the atmosphere, so manuring has a comparatively slight impact on their isotope ratios.

Since crop material is mostly preserved by charring, a further challenge was to establish how this affects nitrogen isotopes. By experimentally charring and then burying modern cereals and pulses, we have found that the effect is modest and predictable. Finally, to remove contamination in ancient crop material introduced over thousands of years in the soil, we adapted methods used to clean charred plant material before radiocarbon dating.

All this set the stage for assessing archaeological crop material. As the results have rolled in, our excitement has grown: archaeological site after archaeological site returned results showing the pervasiveness of manuring in Neolithic farming communities as well as in later, often much more complex, Bronze Age societies.

In prehistory, as today, manure was in short supply, so it had to be used strategically where it could yield the greatest benefit. Unsurprisingly, therefore,

Part of the team in the field, left to right: Michael Charles, Rebecca Fraser, Glynis Jones, Michael Wallace, Tim Heaton.

Amy Bogaard

A cultivated landscape in Asturias, Spain, including spelt wheat plots and piles of manure for spreading.

Amy Bogaard

The author at an experimental site near Aleppo, Syria.

Amy Bogaard

the signals we observe are variable – even, for example, in crops that were harvested in a single year before being destroyed by a catastrophic fire in the storehouse of a Bronze Age community in northern Greece. In fact, there's as much variation as we saw in the villages where we sampled modern crops.

Our results suggest that, while early farming practice was geared towards sustainability, the 'long-term investment' of manuring encouraged families to claim ownership of land, with social consequences culminating in the fixed inequalities of some hierarchical Bronze Age societies.

The story doesn't end there. The very isotope ratios in crops that are affected by manuring will, in turn, affect the long-term formation of nitrogen isotope signatures in the tissues of human and animals that eat them. Stable nitrogen (along with carbon) isotope ratios are routinely extracted from ancient bone to determine the nature of the diet.

Particularly relevant here, differences in nitrogen isotope ratios between humans and associated animal remains are generally interpreted as evidence of their relative position in the food chain – the heavier (^{15}N) isotope gets more common as you move up from prey to predators. The plants people eat, and their livestock or hunted prey, are normally assumed to be isotopically identical, but our modern crop results suggest this is unlikely, for two reasons.

First, manuring creates a disparity between the nitrogen isotopes of crops and those of unmanured wild vegetation. Second, we found systematic differences in isotope values between grain and chaff and other plant parts, which are inedible to humans but can be fed to livestock.

In fact, people and livestock feeding on the same cereal crops but consuming grain and chaff, respectively, would seem to sit around one step apart in the food chain, the grain giving the humans who eat it higher ^{15}N values.

Isotopic analysis of archaeological plant remains alongside those of humans and animals would let us reconstruct ancient diets much more reliably. To do this, we are working to integrate botanical, animal and human isotope values from selected archaeological sites.

We have already discovered that early farmers 'invested' in their plots through manuring. This technologically simple but labour-intensive practice bound cultivation and herding together in resilient forms of small-scale mixed farming. This sustainable kind of agriculture made possible the decisive and irrevocable shift away from hunting and gathering.

By the end of our project, we hope to have transformed our understanding of how our ancestors farmed, ate and lived. But there's still a huge amount to learn about early farming and the role of manuring. Can we discern distinctive regional trajectories in the way agriculture interacted with ecological and social factors over the long term? Were early elites linked with change in agricultural techniques or was there a continuing reliance on small-scale mixed farming, including manuring? We now have the 'toolkit' of methods to find out. ■

MORE INFORMATION

Dr Amy Bogaard is a lecturer in Neolithic and Bronze Age archaeology at the University of Oxford. Email: amy.bogaard@arch.ox.ac.uk

Other members of the project team – Michael Charles, Richard Evershed, Rebecca Fraser, Tim Heaton, Glynis Jones, Amy Styring and Michael Wallace – also contributed to this article.

NEWS

Flu pandemic threatens British sewage works

A severe flu pandemic would send a pulse of drugs into sewage works that could endanger the UK's water treatment system, according to new research.

Sewage works rely on bacteria to break down waste so it's safe to release into rivers. If antibiotics and antiviral drugs make their way through our sewers during an influenza pandemic in the quantity predicted by recent studies, they could have a devastating effect on these bacteria.

An underperforming sewage works would release inadequately-treated sewage into a nearby river, with potentially deadly consequences for fish and other aquatic life. In many areas of southern England, drinking water itself comes from these 'at risk' rivers, so the risk of sewage works failure is immediately relevant to human health.

'The UK's massive antiviral stockpile will expose all UK sewage works and rivers to high concentrations of the drug during a moderate to severe influenza pandemic,' says Dr Andrew Singer at the Centre for Ecology & Hydrology, one of the authors of the report, which is published in *FEMS Microbiology Letters*.

In the first study of its kind, the team exposed a model sewage works to a simulated pandemic, which included an eight-week course of antibiotics and the antiviral drug Tamiflu. They then monitored the sewage works to see how well it kept functioning.

The initial few weeks of the pandemic were manageable, but as the drug onslaught continued, the 'friendly' bacteria lost much of their ability to remove nutrients and clean the water. At the peak of the pandemic the sewage works showed signs of instability and reduced treatment.

Antibiotics were probably the main reason for the bacterial community's decline. These drugs do nothing to cure flu themselves, but can be needed if sufferers develop secondary bacterial infections like pneumonia or bronchitis.

Singer argues that as many people as possible ought to be immunised not just against flu, but also against secondary infectious diseases like bacterial pneumonia, which account for a significant proportion of the sickness and death associated with a pandemic.

Brachiosaurus had the body of a hoover

Dinosaurs like Brachiosaurus, Diplodocus and Brontosaurus may have evolved long necks so they could eat without having to move their massive bodies around so much.

That's the conclusion UK scientists reached after they realised that 1950s-style vacuum cleaners were designed in exactly the same way.

The cylinder vacuum cleaners that were commonplace until the 1970s had heavy bodies with long hoses. They were meant to be positioned in the middle of a room while the operator moved a light head-part at the end of the hose across the surrounding carpet.

All of the sauropod dinosaurs that lived from 200 million years ago until they went extinct 65 million years ago also had heavy bodies with long necks.

'The general assumption in the scientific community was that long necks would have been useful for reaching hard-to-reach foliage, just like a giraffe,' says Professor Graeme Ruxton from the University of Glasgow, who led the study published in *Biology Letters*.

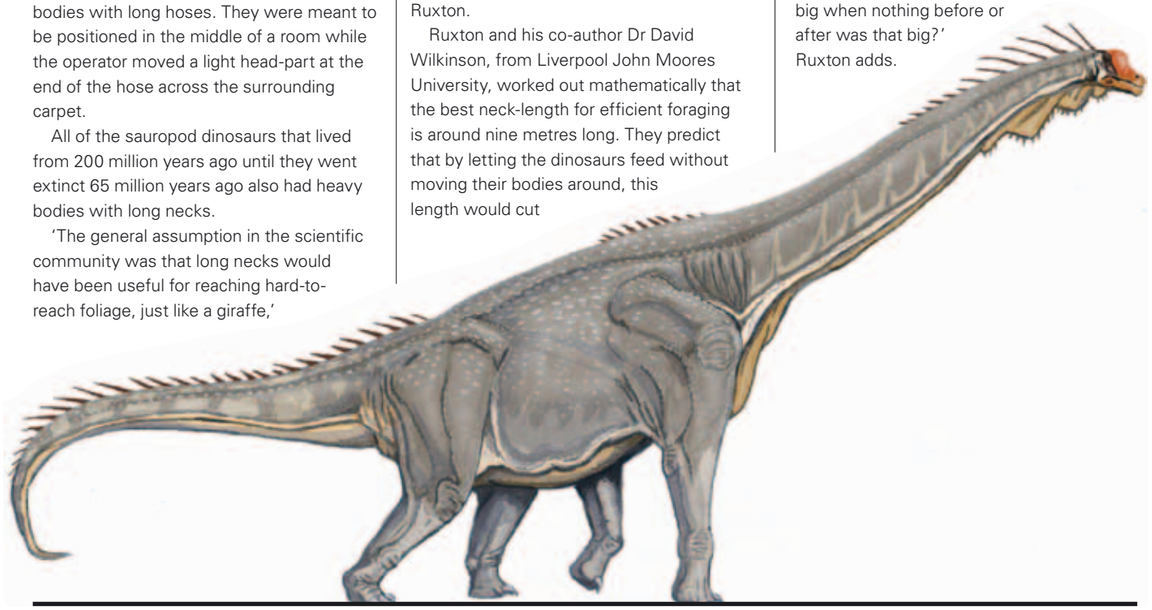
But some palaeontologists think the dinosaurs' blood pressure couldn't have been high enough to get blood along its eight-metre-long neck to its brain if it was feeding like this.

Not only that, but 'most sauropods have shorter front legs than back legs – it doesn't seem to fit with high browsing,' says Ruxton.

Ruxton and his co-author Dr David Wilkinson, from Liverpool John Moores University, worked out mathematically that the best neck-length for efficient foraging is around nine metres long. They predict that by letting the dinosaurs feed without moving their bodies around, this length would cut the energy costs of foraging by a huge 80 per cent.

The tough, fern-like plants the dinosaurs ate would have needed a lot of digesting and the sauropods' small heads couldn't have held enough teeth to pre-process their food by chewing. So their large bodies may partly be the result of needing a lot of space for digestion.

'But the bigger question we've yet to answer is why did these dinosaurs get so big when nothing before or after was that big?' Ruxton adds.



NEWS

Protein remains revealed in ancient reptile skin

Scientists have produced unique images of protein residues in 50-million-year-old fossilised reptile skin.

University of Manchester geochemists and palaeontologists used a technique called infra-red spectroscopy to produce the stunning images of the molecules called amides, which are only found in proteins.

The residues – in a sample of 50-million-year-old rock from the Green River Formation in Utah, USA – are in the same place that you'd find them in modern-day reptile skin.

'If you compare these infra-red images with the same images of gecko skin, it's hard to tell the difference,' says Dr Roy Wogelius from the University of Manchester, who led the research.

The two areas of science are so different that no one had ever thought to use infra-red mapping to analyse fossils before.

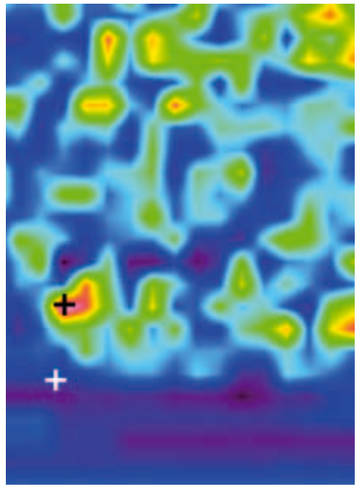
'This technique is perfect for identifying functional groups in proteins like we've got here,' says Wogelius.

Until now, most palaeontologists would have assumed that these organic compounds probably came from bacteria. But the compounds the team found were dominated by material from the original organism.

'We found amides and it's also chock-full of trace metals, which tells us how these protein residues must have been preserved,' Wogelius explains.

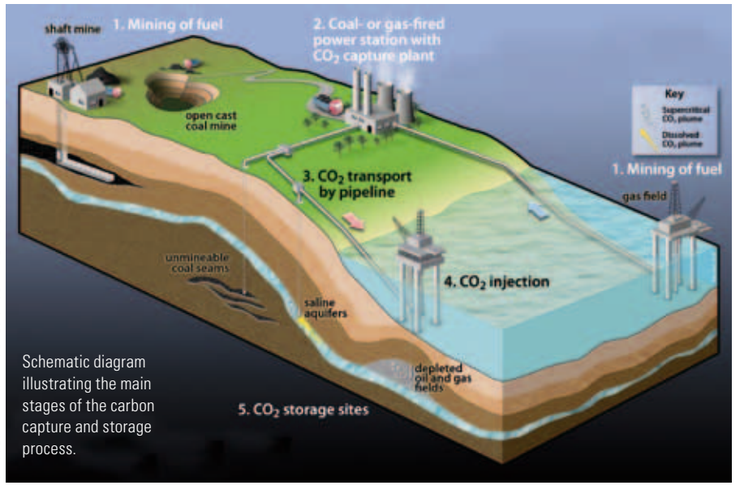
When proteins start disintegrating they bind to minerals in the rock, which makes them stable and unlikely to get washed away by water.

Another advantage of the technique is that you don't need to destroy the precious sample you're analysing to get a result. The study is published in the *Proceedings of the Royal Society B*.



Infra-red mapping of the skin suggests how the sample was preserved.

Study reveals Scotland's carbon capture and storage potential



Schematic diagram illustrating the main stages of the carbon capture and storage process.

Scottish Centre for Carbon Storage, School of GeoSciences, University of Edinburgh

The rocks deep beneath the Moray Firth could store decades' worth of carbon dioxide from Scotland's power stations, a report reveals.

This emerging carbon capture and storage industry could create thousands of new jobs within the next few years, and bring many economic and environmental benefits to the UK.

The research calculates that rock buried more than half a mile beneath the Moray Firth and known as 'the Captain Sandstone' could store at least 15 years' worth of CO_2, and more likely as much as a century's worth.

Dr Maxine Akhurst from the British Geological Survey is the project leader for the research, carried out by Scottish Carbon Capture and Storage (SCCS).

'Even if you apply the most stringent geological conditions, the worst case scenario will mean that we could store 15 years' worth in a single sandstone, and there are a number of the Captain Sandstones suitable for storing CO_2 beneath the North Sea,' she says.

'The sandstones are huge,' adds Akhurst. 'A small sandstone would be the size of a county such as Hampshire, and a large sandstone would be about the size of Belgium.'

Professor Eric Mackay from SCCS agrees the site would help the UK meet its targets for reducing its carbon emissions. 'This is an exciting and landmark moment in the development of carbon capture and storage.' he says. 'The future potential for this and other areas of the North Sea is immense.'

The research showed that carbon capture and storage could create around 13,000 jobs in Scotland by 2020 and another 14,000 elsewhere in the UK, spread across a wide range of skills. Properly developed, the UK's share of worldwide carbon capture and storage business could be worth more than £10 billion a year by about 2025.

Per H. Olsen

Hawk-like plumage gives cuckoos an advantage

Scientists have found that as well as craftily laying their eggs in other birds' nests, cuckoos have another trick up their sleeves.
If a cuckoo's plumage looks like a hawk's, hosts like the reed warbler are less likely to attack them as they try to lay eggs in their nests.

Cuckoos are so-called brood parasites – they lay their eggs in other birds' nests to avoid the trouble of raising their own chicks. A newly-hatched cuckoo chick then turfs the hosts' eggs or young out of the nest.

But how does the cuckoo manage to lay its eggs in reed warblers' nests in the first place?

'Reed warblers are afraid of sparrowhawks, which are lethal birds of prey, and cuckoos exploit this by mimicking the sparrowhawk's barred underparts,' says Dr Justin Welbergen from the University of Cambridge, lead author of the study, published in *Behavioral Ecology*.

If parent reed warblers think a sparrowhawk is near their nest they keep out of the way – so the intruding cuckoo is free to lay her egg without being mobbed by the hosts.

'Ironically, having a cuckoo lay its egg in your nest is very costly and compares to being attacked by a hawk,' says Welbergen.

The researchers showed taxidermic models of sparrowhawks and cuckoos to wild reed warblers, either with their barred plumage showing or covered with white fabric. They then recorded the sounds the birds made and watched to see if they mobbed.

They found the reed warblers were more reluctant to mob the cuckoos which had their barred bellies showing – so the cuckoos' hawk mimicry does give them easier access to reed warblers' nests.

in brief . . .

Sharks visit personal hygienists

For the first time, thresher sharks have been seen in shallow waters near the Philippines, being groomed by small fish known as cleaner wrasse.

The sharks swim in slow circles in a particular area to attract the wrasse.

'On the reef there are fixed stations, or focal points, where cleaner wrasse can be found,' Simon Oliver from Bangor University explains. 'These fish are very selective about their clients so we think the sharks recognise the focal points where their particular cleaners operate.'

'The sharks come in with cuts and scrapes and are treated by the cleaner wrasse, which remove dead tissue from the wound area and any parasites from the skin. These stations are quite critical to the health of reef communities,' says Oliver.

The research is published in *PloS ONE*.

Leeds project to tackle virus

Scientists at the University of Leeds are to investigate how lethal viruses attack moths and butterflies, in research that could lead to better ways to control pests and manage invasive species.

Dr Steve Sait from the University of Leeds and Professor Rosie Hails from the Centre for Ecology & Hydrology will study the grain-infesting Indian meal moth (*Plodia interpunctella*) and a virus it carries that is sometimes deadly to its host and sometimes not.

The Indian meal moth is a significant problem around the world, attacking harvested crops such as cereals, rice, nuts and seeds and manufactured foods such as chocolate.

The art of ancient oceans

A new exhibition at University College London aims to make the complexities of palaeo-oceanography accessible to a wider audience.

The discipline involves reconstructing ancient oceans and climates through the traces they've left behind, such as the remains of tiny single-celled organisms, built up over millennia into thick rock deposits.

The exhibition brings art and science together, explaining how different research methods contribute to understanding past environments with clear text and striking images that show the beauty and diversity of the microfossils on which much of the team's science is based. It stems from work done on the Tanzania Drilling Project.

The Hidden World of Past Oceans runs until 11 August, and is open to the public in UCL's South Cloisters; admission is free.

Most people have heard of forensic science, made popular by TV dramas like *CSI* and *Cold Case*. But the contribution of organisations like the British Geological Survey (BGS) – better known for responding to natural disasters – remains behind the scenes. Marion O'Sullivan finds out how BGS geologists turn detective.

CBS/Everett/Rex Features

Adventures in geoforensics

It's five o'clock on a Friday evening and scientist Julian Trick is thinking about calling it a day when the phone rings. It's the UK police National Search Adviser, Mark Harrison, and he needs some expert help on a case.

'Mark always rings at five o'clock on a Friday,' says Trick. 'When he calls us he's usually working on an old case that hasn't been solved. There are limited resources available for these cold cases, and no real urgency, so he takes them forward whenever he has a spare moment – usually evenings and weekends. He likes to have a single point of contact at BGS – me – and then I contact the relevant people to work with him.'

Professor Mark Harrison is a senior police officer and a professor of geo-forensics. He has worked with BGS scientists for a number of years, so when he's called in to solve this case he knows they will be able to help. Unusually, this time it's not a cold case but a current investigation.

A man has disappeared without trace and has been missing for several weeks. The local police suspect murder and have made an arrest – the suspect denies being there, but a smear of his blood has been found at the missing man's home. But what has happened to the man – and if he is dead, where is the body?

This was the dilemma police faced on the remote Orkney island of Sanday in 2009. Under Scottish law there can be no murder conviction without a body. Police found sand on the suspect's vehicle and thought that he and an accomplice had buried the body, but there was no other evidence.

Harrison knew that BGS would be able to help, by finding the origin of the sand found on the vehicle, and identifying the most likely places a body could be buried. The scientists produced a geological map of the island, overlaid with maps of sand and soil types, roads and urban areas. Then, using a colour-coded system they and Harrison had developed, they created a RAG map (Red/Amber/Green) with green areas representing the hardest, least accessible soils (the most unlikely places to hide a body), amber areas showing possible places to dig, and red showing the most obvious areas to search.

'When I phoned BGS that Friday I didn't tell the scientists what I suspected as that might have contaminated their thoughts and led them in wrong directions,' says Harrison. 'So I only told them what they absolutely needed to know. Because this was an active investigation some of the details were confidential anyway, and I didn't want them turning into amateur detectives and trying to solve the case for me.'

Within an hour, forensic geoscientist Russell Lawley and his colleagues had emailed the RAG map to Harrison.

'Using geology is not about trying to find the needle in the haystack, but trying to reduce the size of the haystack,' explains Lawley. 'Our map played a small role in this case as Mark was also using other detection methods, such as thermal imagery and a dog that had been trained to find bodies. The map showed the most likely place to look and, once the search was switched to that area, the cadaver dog very quickly found the victim's body buried in a shallow grave.'

'This case was very uncomfortable for us, as we were watching the story unfold in the news and we knew that we were helping to find someone's father or brother … We usually work on very old cases where there are unlikely to be any close relatives still living.'

One such cold case that Lawley, Trick and colleagues have been working on relates to the disappearance of 16-year-old Emma Alice Smith in 1926. The teenager was last seen setting off on her bicycle from her home in Waldron, East Sussex, to catch a train to work. She was never seen again and, after an initial search failed to find her or her bicycle, it was assumed she had run away.

Police reopened the case in February 2009, when a deathbed confession from 1953 came to light. The dying man had confessed to a relative that he had murdered the young girl and dumped her body and the bicycle in a local pond. The confession remained a secret for more than 50 years.

'Over time the landscape changes and features that were there in 1926 may not be there now. The pond may have been filled in, for example,' says Lawley. 'But we have historic maps, plus the technology and expertise to look at where the pond might have been.'

BGS has been creating geological maps for 175 years. These began as beautifully hand-painted watercolours, then printed and more recently web-based versions. The latest maps are now available on a smart-phone app – iGeology. As the technology has evolved, so have the ways in which geological mapping can be applied.

BGS worked with virtual-reality specialists Virtalis, to develop software that allows the scientists to investigate landscapes from the comfort of their offices. The scientists can overlay geochemical maps, road networks and the like over aerial photographs covering the whole of the UK. They view these in a 'visualisation suite', where 3D images can be projected from floor to ceiling.

'It is an incredibly powerful virtual reconnaissance tool,' says Trick. 'Think Google Earth, flying around in a helicopter wearing 3D glasses. Your avatar can walk around in a virtual world, fly through landscapes and also dive underground where it can find concealed caverns or deep-water lakes.'

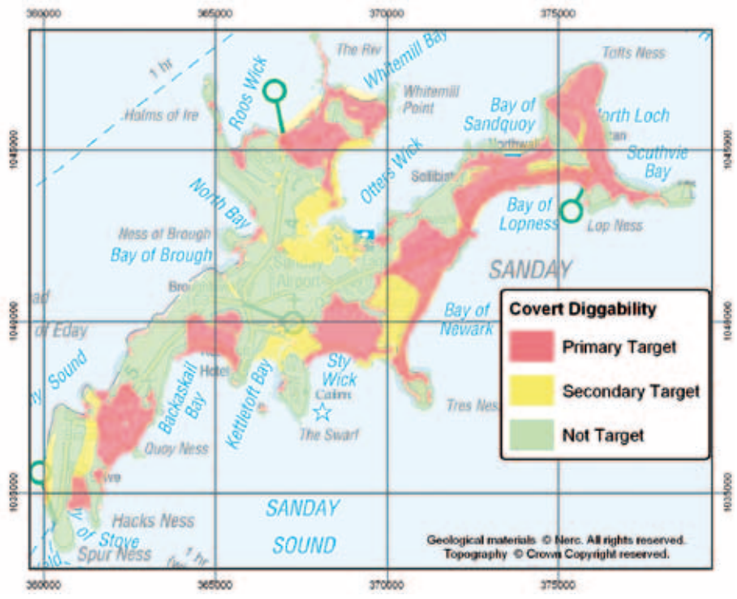
The GeoVisionary maps can test for 'line of sight' visibility on the surface, so they can look for potential witnesses to crime and confirm what they might have seen, depending on their position. They can also find deep lakes or reclaimed quarries and, by overlaying the maps with accessibility or slope-analysis tests, they can work out if they are deep enough to conceal a vehicle – or a body and a bicycle.

Lawley comments: 'We can visit an area in virtual reality, as if we were under an invisibility cloak, and no one will ever know we've been there. It's an amazing piece of technology.' This same technology may help to lay Emma Alice Smith to rest.

'Our work with the police helps the public good and goes hand in hand with our bread-and-butter work,' says Trick. 'We don't do it every day, so when we're called in to work on a case it's exciting and novel for the scientists. We can find small pieces of evidence which, when added to existing knowledge, help to build the bigger picture. It's very rewarding to know that our science can find concealed objects or place a perpetrator at a crime scene.'

One thing is for sure – the technology and methods used in forensic geology have come a long way since 1887, when fictional detective Sherlock Holmes identified the origins of the mud on his fellow travellers' shoes. ■

An example of a RAG map.



Scientists using the GeoVisionary technology.

MORE INFORMATION

Professor Mark Harrison MBE was until recently national search adviser for homicide, missing persons and mass fatality disasters for the UK police. He now leads a division of the Australian Federal Police.

Julian Trick and Russell Lawley are geoscientists based at BGS Keyworth, Nottingham.
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FURTHER READING

Britain beneath our feet: **www.bgs.ac.uk/education/britain_beneath.html**

iGeology: **www.bgs.ac.uk/igeology**

The coolest job on the planet?

When people ask Jonathan James (right) what he does for a living the response is often: 'what on Earth for?' But he thinks working on the largest, highest, coldest and windiest continent on the planet is incredible. The British Antarctic Survey diver shares his first winter under the ice.

It's difficult to describe what it's like working here. Just being in this environment is amazing and my job as a diving officer for BAS enhances that experience tenfold.

I work at Rothera Research Station, which is home to up to 120 people in the Antarctic summer, between October and March, and a team of 22 over the winter. Rothera lies just west of the Antarctic Peninsula, on the coast of Adelaide Island, and provides a year-round base for scientists studying atmospheric, terrestrial and marine science. Maybe I'm biased, but the marine science can be the coolest – quite literally. There's a year-round team of four divers plus visiting scientists over the summer, and our diving projects mainly focus on long-term monitoring. This means things like monthly photography of deep and shallow settlement plates at different dive sites. These small plastic plates mimic a newly iceberg-scoured part of the seabed and they're used to see what types of organisms colonise the plate over several years. Tiny spirorbid worms are the first occupants (these generally cover everything!), then coral-like bryozoans which like rocky surfaces, then anything that feeds on the above such as limpets, starfish and larger worms. It's a succession of colonisation, but plates at different depths are inhabited by different types of organisms at different speeds.

We also monitor data loggers at two dive sites around 20m deep, to record detailed monthly temperature changes and collect specimens for experiments on base and back in the UK. Some of these samples are used for thermal-limit studies – to see how organisms react to changes in water temperature in an aquarium and predict how they might cope as global warming increases. Another experiment looks at how organisms cope with changes in oxygen levels.

I've spent two summer seasons here but this is my first winter. Some of the summer dive conditions compare with the murky waters of the UK's Plymouth Sound, but others have been extraordinary. In the peak of summer the plankton blooms reduce underwater visibility, sometimes to barely a metre. This makes photography problematic to say the least, and collecting small creatures even more of a frustrating task, as if it wasn't hard enough with thick neoprene mitts on. There are big advantages to these summer dives, though; whether it's been luck or coincidence, the weather has been pretty outstanding. Clear blue skies and 24-hour sunlight make for some of the best landscapes imaginable, and the dive boat seems very insignificant against the backdrop of Adelaide Island's towering ice cliffs and the distant mountain ranges of the Antarctic Peninsula. When you're acting as surface support for the divers you get the chance to appreciate not just the scenery but also the abundance of wildlife. One minute there's a pair of snow petrels flying around the boat, the next you spot the arched backs of a group of humpback whales slowly cruising past just a few hundred metres away. At these moments everyone on the boat is thinking one thing…who has a camera?

Chilling out

I've discovered a few key points about winter diving so far. When you can hear wind whistling past the dining room window and it's pushing 50 knots on the weather report, you reconsider walking to the next building let alone launching a boat. Then there's the light: at the moment it's near the end of May and we're getting around four to five hours of dusky sunlight. But soon the sun will dip below the mountains for the last time and for a couple of months we'll have a mere two or three hours, significantly reducing our dive window. Next, if you forget your beanie or balaclava you're in trouble, as the ice-cream headaches you get on the boat ride back can be pretty painful! These things make it tricky to plan a day's diving, but when you get out there it's not just good: it's amazing. Once you've warmed tractor, crane and boat engines, bulldozed snow out of the way, rushed out with all your dive kit hoping that the engines haven't frozen up again, checked that there are no leopard seals or orcas nearby, and put all the dive kit on…you roll backwards into gin-clear waters and escape. For half an hour you're beneath the surface, diving down 20 metres into a different world.

Under the ice!

A lot of people ask me if I get cold when I'm diving. To be honest when I'm under water, the only things that get cold are my hands and feet. But if the dive involves a lot of swimming around, in the summer I can manage an hour under water without getting too cold, provided I have the air.

One thing that I've yet to encounter this winter is sea ice and the trials and tribulations it throws up. We've had the risk assessments and sea-ice travel training, and learned about ice-depth measurements and weather restrictions, and, I do know we'll be cutting holes through ice with a chainsaw before we can make our dive. This sounds pretty entertaining, but the best bit is we get to take the novelty picture of walking upside down under the ice! There are times when it is possible to dive through much smaller, football-sized chunks of brash ice – the broken-up ice that's present most of the year round. Brash ice can make it difficult to manoeuvre the boat, but the view up through it while you're on your safety stop can be pretty amazing, especially on a bright day.

It's not all work and no play here at Rothera. In the evenings I can relax in warm, comfortable buildings and even visit the sauna – next to the mechanic's garage – to warm up after a cold day out. When the weather's bad some people (occasionally even me) get some exercise in the gym where there are regular circuit training and yoga sessions, before enjoying a hot meal and maybe a film in the TV room. And on fair-weather days, we get the chance to venture off base to safe areas nearby for skiing and snowboarding; if you speak nicely to the mountaineers you might even get a climb up the nearby ridges and hills.

At these moments everyone on the boat is thinking one thing…who has a camera?

The highlight for those of us here over the winter, though, is the midwinter's day present. This is a great tradition here at Rothera where people are away from home for such a long stretch. We pick names out of a hat and everyone goes to great efforts to hand-make a present for the person they've picked. My gift project so far has involved chiselling my finger and making a number of 'slightly' misplaced wood cuts, but I'm hoping they can all be disguised once it's finished!

I feel very lucky to be doing this job. Being away from friends and family can be difficult for a year and a half, but it's an opportunity not to be missed. Everyone remembers where they were when they were accepted for this job and, believe me, it leads to a lot more moments you will never forget. ■

MORE INFORMATION
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Biofuels:

weighed in the balance and found wanting

Growing crops for bioenergy could help cut greenhouse gas emissions from burning fossil fuels, but to plant them we first have to clear the existing natural vegetation, and this itself gives off carbon dioxide. If we planted them widely, would the overall effect be beneficial? Amanda Lloyd, John Hughes and Chris Huntingford set out to find the answer.

Dr Colin Lloyd/CEH Fellow

By combining data and climate models, the latest United Nations Intergovernmental Panel on Climate Change (IPCC) assessment says that humans are 'very likely' to be causing the warming observed over recent decades.

This is mainly through increases in concentrations of atmospheric greenhouse gases – primarily carbon dioxide (CO_2) – from burning fossil fuels. CO_2 levels have increased by over 100 parts per million by volume (ppmv) since pre-industrial times, reaching about 385 ppmv.

Things like ice-core records, where trapped bubbles of air can tell us about past atmospheres, suggest that this is higher than anything experienced on Earth in 800,000 years. If we continue using fossil fuels this way, climate models predict that by 2100, global average temperatures near the surface could increase by something like 5°C compared to pre-industrial times. Such warming over such a short period would have catastrophic effects on planetary processes and have a serious impact on society.

Using crops as an energy source is one possible way to reduce future CO_2 emissions. The concept is simple – as plants grow, they take in CO_2 through photosynthesis. If we then burn these crops to generate energy, the CO_2 released will have been very recently taken out of the atmosphere, unlike mined fossil fuels, and more will be absorbed as the next season's crop grows. Therefore using energy crops should, in theory, give lower CO_2 levels in the future because energy needs can be met without burning quite as much fossil fuel.

But there are many questions that need to be discussed about large-scale planting of energy crops. For instance, we have to balance the need for energy against the requirement for space to grow food. In terms of the carbon cycle, clearing natural vegetation to make space for energy crops usually releases carbon that was previously stored in both the plants and the soils they were growing in.

Balancing the carbon benefit from growing energy crops against this initial release of stored carbon into the atmosphere is a vital scientific question. Indeed, the number of years it takes before the released CO_2 is balanced by the reduction in CO_2 emissions from fossil-fuel use is referred to as the 'payback' time. If this came only after many centuries, then growing energy crops would be pointless – it would actually increase global warming through the 21st century.

It's payback time

We analysed the problem, attempting to characterise energy crop payback times. The crop we chose was *Miscanthus x giganteus*, described as a 'sterile hybrid perennial rhizomatous' C_4-grass species. In a nutshell, that means a hybrid plant, created from two other species of *Miscanthus* (*Miscanthus sinensis* and *Miscanthus sacchriflorous*), that is infertile and can only propagate through its rhizomes.

Rhizomes are a plant's horizontal underground stems – one well-known example is ginger root. *Miscanthus* uses nutrients, sunlight and water very efficiently, so it is a particularly attractive energy crop that grows quickly and needs few external inputs like fertilizers.

If payback came only after centuries, growing energy crops would be pointless – it would actually increase global warming.

This high efficiency centres on its use of what is known as the C_4 photosynthetic pathway. Plants can photosynthesise in several different ways; this one lets them use more of the light that is available to them, and convert and store this energy more efficiently. For the past four years, we have conducted field experiments with *Miscanthus* in Lincolnshire, to measure this crop's physiological parameters: its canopy height and leaf area; its land-surface heat balance – that is, how much of the sun's energy is divided into components that include evaporation, heating the air, vegetation and soil and energy for photosynthetic growth within the *Miscanthus* crop. Most important of all these parameters are its carbon fluxes – how much CO_2 it extracts from the atmosphere and locks into its leaves, stems and roots.

At the same time, we have taken micro-meteorological measurements of the surface weather: sunlight, air temperature, humidity, rainfall and wind speed, which are known to have a strong influence on physiological responses and thus on carbon fluxes. These measurements let us configure the models of energy crops, so that we can predict different growth rates based on local weather characteristics. We can ultimately determine how much CO_2 we expect to be drawn down from the atmosphere, in a broad range of different places.

This understanding of how *Miscanthus* behaves is then fed into the Met Office Surface Exchange Scheme (MOSES) computer model of land-surface processes such as water balances (rainfall, snow, evaporation and soil wetness), radiative processes (sunlight and thermal radiation) and the land-surface heat balance. With *Miscanthus* included in MOSES, we can then calculate *Miscanthus* crop behaviour across the globe using another model, called IMOGEN.

IMOGEN calculates changes in the surface climate that would be caused by given changes in atmospheric greenhouse gas concentration, and provides the weather data that MOSES needs. Using this setup, we can work out the growth rate of *Miscanthus* for many regions of the world and for various levels of climate change.

As IMOGEN-MOSES also simulates the behaviour of the plants and soils that make up the natural terrestrial carbon cycle, we can calculate the balance between natural carbon lost against the carbon benefits of harvesting *Miscanthus* in different places, thus producing global maps of the payback times.

What have we found? Our research shows that it can take many decades before planting a typical energy crop plantation starts to reduce atmospheric CO_2 levels. This is because the initial planting removes carbon in the existing soil and vegetation and returns it to the atmosphere. The exact payback time depends on where the plantation is, and what kind of vegetation has to be removed to plant *Miscanthus*.

Over the Amazon, for example, the average payback time is 14 years because the favourable climate means the energy crops can photosynthesise more quickly, while for Europe the average payback time is 37 years. This means removing natural vegetation – forests and woodland – to plant crops will not reduce CO_2 levels for decades to come. However, planting on degraded land (such as former industrial sites and landfills) where possible could minimise this initial loss of CO_2, as in these areas there would be less natural vegetation to be cleared.

This research provides guidance to national and international efforts to mitigate emissions of CO_2 using energy crops. This initial analysis gives a 'broad brush' global picture. Next, we plan to provide additional verification of how the *Miscanthus* crop responds to local weather, and investigate other possible crops, which may react completely differently to *Miscanthus*, especially if these plants use the C_3 photosynthetic pathway (a much less efficient system) in significantly more detail at a regional scale.

The findings from this research may mean that policy-makers need to consider the specifics of each case and not assume what is true in one part of the world is true elsewhere. The strong geographical variation in payback time suggests that biofuel crops may be beneficial in some places, though, and as part of an overall package of alternative energy sources to deal with climate change. ■

MORE INFORMATION

Dr Amanda Lloyd is currently a member of the Institute for Marine Resources and Ecosystem Studies (IMARES) at the University of Wageningen in the Netherlands. Dr John Hughes works in the terrestrial carbon cycle modelling group at the Hadley Centre for Climate Change Research. Dr Chris Huntingford works as a climate modeller at the NERC Centre for Ecology & Hydrology. Email: amanda.lloyd@wur.nl

FURTHER READING

This work was published in *Global Change Biology Bioenergy*; the journal and has kindly allowed free access for a limited time.
J K Hughes, A J Lloyd, C Huntingford, J W Finch, R J Harding. The impact of extensive planting of Miscanthus as an energy crop on future CO_2 atmospheric concentrations. *GCB Bioenergy* (2010) 2, 79-88.
http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1757-1707

The IMOGEN model is published in the open access journal *Geoscientific Model Development*, and thus freely available:**www.ceh.ac.uk/staffwebpages/documents/huntingford_et_al_10.pdf**

C Huntingford *et al.* IMOGEN: an intermediate complexity model to evaluate terrestrial impacts of a changing climate. *Geosci.Model.Dev.* (2010), 3, 679-687.

Left: Miscanthus crop with instrument tower measuring energy and carbon fluxes.

Some like it cold

Penguins have thrived in Antarctica's extreme environment for thousands of years, but they still rely on relatively stable weather and ice conditions, and those conditions are changing. Jaume Forcada reveals how a penguin's lifestyle influences its resistance to climate change.

Penguins are one of the most common seabirds in the Southern Ocean. Their size, shape and other traits make them well adapted to the extreme conditions of sea and ice they live in, and some species live in huge colonies. Their environment determines the quantity and quality of their food and the availability of their preferred breeding and resting places. So a penguin's way of life is restricted to a closely defined set of conditions, and as a group this makes them particularly sensitive to climate change.

When changes in climate affect the penguins' environment – for better or worse – they have to adapt, especially when their critical habitats are affected. But penguins don't all have the same lifestyles, so does this mean some species will respond differently to others as the Antarctic environment changes? Together with colleagues at the British Antarctic Survey, I have been trying to find out.

Eight of the world's 17 penguin species live in the Southern Ocean. All but two of these 17 are ice intolerants, which means they live on ice-free land and ocean. Adélie and emperor penguins are ice-obligates: they rely on the sea ice and can live in the most extreme environments. Emperors in particular can survive some of the harshest weather on the planet. The species differ in other aspects too, for example, their breeding chronologies – in other words the timing of arrival at their breeding site, egg-laying, chick fledging and moulting in adults.

To find out how these different lifestyles might influence the penguins' response to climate change, we gathered almost 30 years of continuous records of the lives of penguins across the Scotia Sea, in the south-west Atlantic sector of the Southern Ocean. We used historical records and information gathered by our own colleagues in the field, to take a closer look at the macaroni and

Clockwise from far left: Gentoo penguins in South Georgia, chinstrap penguins and Adélie penguins, both on the South Orkneys.

gentoo penguins of South Georgia, and the gentoo, chinstrap and Adélie penguins of the South Orkney Islands.

Conditions in the Southern Ocean vary distinctly with the seasons, and this seasonality is crucial for the penguins. It defines the spring/summer window when there is enough food and the right habitat for breeding.

But this seasonal window is becoming less reliable, as global warming affects the complex interaction of ocean and air currents that influence the temperature and sea-ice conditions of the Southern Ocean. If the window changes, it can have a profound effect on the ability of the birds to hatch and rear healthy young – but it will have different effects depending on the particular lifestyle of the species.

If they haven't found enough food they'll be in very poor condition and can literally starve during the moulting period.

For example, Adélie penguins live on sea ice but need ice-free land to breed. They migrate thousands of miles to reach their breeding grounds then return to the sea ice to moult. They arrive in the breeding grounds in October or November, at the start of spring – any later and their journey becomes increasingly dangerous as the melting sea ice increases the distance they have to travel to their moulting locations on the solid pack ice. In contrast, gentoo penguins do not migrate as far as the Adélies, and because they are closer to their breeding areas year round they can be more flexible about when they breed.

In years of increased snow storms in the South Orkneys and the West Antarctic Peninsula, incubating birds can literally be covered up to the neck in snow. When the snow melts in summer the nests are flooded and the eggs die. If the penguins can rebuild their nests, as gentoo penguins seem able to do, they will have another chance to breed. For Adélie penguins, which are more constrained by the ice cycles, this will be a real problem and they will invariably fail.

Over our long study period, the chinstrap and Adélie populations of the South Orkneys have declined significantly, but gentoo penguins have increased in number. These trends appear to go hand in hand with warmer, more variable weather and a more variable climate.

These same factors also impact on the penguins through their effect on the birds' main source of food – krill. These small, shrimp-like creatures sustain millions of Southern Ocean predators, from fish to whales. Many penguins depend directly on krill, or on fish species that feed on them, and if they don't get enough they will be under nourished at breeding time and more likely to produce weak chicks that don't survive.

A big reduction in krill could also mean the birds don't have enough resources to be able to moult their feathers. The moult is a critical period because all penguins need to shed their old, worn-out feathers and get a new coat to survive the winter, and this usually happens right after breeding. The moult lasts for a few weeks and the birds fast while it's happening, so they must build up fat before the moult starts. If they haven't found enough food they'll be in very poor condition and can literally starve during the moult – as we have seen for ourselves in years when krill is in short supply.

For the ice-obligate Adélie penguins it's even worse, because they need to reach the hard pack ice for their moult. In bad years not only is food scarce, but the pack ice retreats farther south in the Weddell Sea, very far away from the Adélies' breeding colonies in the South Orkneys. The penguins have to swim much farther to reach the ice in time to start moulting, and if they haven't been able to find enough food beforehand they will be very weak when, or if, they arrive.

Studies of penguin remains – some thousands of years old – from abandoned or old penguin colonies, suggest that the birds have responded to climate change in the past by temporarily adopting new habitats, or by permanent migration. We think we're going to see similar responses in modern penguin populations that are living at the edge of their current geographic range – and therefore at the limits of their tolerance to change.

Our work shows that some penguin species are already feeling the effects of changes to their habitats, and while some suffer others appear to be much more adaptable. With increasing variability in regional climate, particularly rapid warming, penguins may continue to live across their current geographic range if they can adapt to the new environment. So those penguin species that can find alternative food, and are flexible enough to breed in different habitats and at different times, are going to be the winners in a warmer Southern Ocean. Over the longer term they might even evolve in response to these changes.

Given their location and the types of penguins that live there, our sites will give us an excellent opportunity to test this theory. ■

FURTHER INFORMATION
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NEWS

Ozone damage to vegetation influences global warming

Pollutants from cars and paints can warm the Earth's atmosphere when they turn into ozone and damage plants, a new study has found.

These short-lived pollutants – like nitrogen oxides and volatile organic compounds – have little direct impact on temperature, but they react in the atmosphere to form the greenhouse gas ozone. Among other things, too much ozone damages plants, making them less good at photosynthesising carbon dioxide from the atmosphere and storing – or sequestering – it in the ground.

'It's been well known for a long time that ozone damages plants,' says Dr Bill Collins of the Met Office Hadley Centre, who led the research, 'but no one has made the connection with ozone damage and the effects on the movement of carbon between the earth and the atmosphere.'

The team ran a sequence of models to predict the effects of three pollutants – nitrogen oxides (NOx), carbon monoxide (CO) and volatile organic compounds (VOC) – on the Earth's temperature. They looked at how these chemicals affect vegetation across the northern hemisphere.

One of the most surprising effects was for NOx, which scientists usually think of as a cooling pollutant because it reduces the warming effect of methane in the atmosphere. But under some conditions the contribution of plant damage was strong enough to turn this around, and this meant the gas warmed the atmosphere overall.

Ozone damage on a clover leaf.

In combination, reducing emissions of all the pollutants cooled the climate. Significantly, this cooling effect is 30-40 per cent greater than when plant damage is excluded from the calculations. 'This gives us another good reason to control air pollution,' comments Collins.

The study's results, published in the *Journal of Geophysical Research*, are for a global average temperature.

Parasite competition offers new insight into malaria

Scientists have shown how parasites change behaviour when confronted by other strains of the malaria infection in their host.

The study, published in *American Naturalist*, shows how the malaria parasite focuses on producing cells that replicate quickly to cause infection, rather than cells that can be taken up by a feeding mosquito and spread the disease.

Since malaria infections usually consist of multiple, competing strains of the parasite, this attack strategy is the best way to beat the competition.

Explaining how parasites behave inside their host helps us understand the severity of a disease and how it will spread – particularly important for malaria which kills about a million people each year and threatens half the world's population.

Red blood cell bursting after infection of malaria.

Albert Bonnier s Forlag

'If the mechanisms underlying these behavioural changes in malaria parasites can be identified,' say the researchers, 'it may be possible to manipulate their behaviour in clinically beneficial ways.'

Malaria is caused by single-celled parasites which replicate in the red blood cells of their host, and are taken up and spread by mosquitoes. Malaria parasites replicate asexually in the host but must reproduce sexually to move between them.

All organisms must balance resources between, for example, finding food and reproducing. In malaria's case this means a trade-off between replicating within one host or spreading to a new one.

... it may be possible to manipulate their behaviour in clinically beneficial ways.

The international team of researchers studied the malaria parasite *Plasmodium chabaudi*. They found that, when more than one strain of the parasite was present, they chose to safeguard their long-term survival.

'They opt to fight it out in the bloodstream rather than risk everything on the chance of infecting mosquitoes in the short term,' said Laura Pollitt of the University of Edinburgh's School of Biological Sciences, who led the study.

Climate change increased the odds of autumn 2000 UK floods

Chris Ison/PA Archive/Press Association Images

Climate change substantially increased the likelihood of the autumn floods in 2000, which damaged almost 10,000 properties and led to insured losses worth an estimated £1.3 billion, according to a study published in *Nature*.

By running a Met Office climate model thousands of times researchers simulated the weather patterns seen during 2000 and compared them with simulations of those we would have experienced that year if atmospheric carbon dioxide had stayed at 1900 levels.

In nine out of ten comparisons, the presence of 20th-century greenhouse gas emissions increased the risk of floods in England and Wales by 20 per cent or more. And in two thirds of cases, the increase was 90 per cent or more.

Until now scientists have only been able to suggest in general terms that climate change will bring more episodes of extreme weather, simply because a warmer atmosphere can hold more water. This is the first study to look in detail at how much greenhouse gas emissions increased the risk of flooding over a particular period.

'It's like rolling a die,' explains Dr Pardeep Pall, an atmospheric physicist at the University of Oxford and the paper's lead author. 'You might roll it once and get a six, but it's very difficult to say why this happened, or how likely it was. To start building up a picture of how probable a particular outcome is, you need to roll the dice again and again, and that's what we are effectively doing by running the climate model thousands of times.'

The resulting range of rainfall values was then fed into a model from Risk Management Solutions Ltd, a company that develops risk models for the insurance industry. This model simulates how water drains off the land and into watercourses, to estimate the risk of flooding.

The team drew on computing power supplied by volunteers all over the world, using the infrastructure of the climate*prediction*.net project, which uses so-called 'distributed computing' to improve predictions of the future climate.

Climate*prediction*.net has now launched a follow-up project called weatherathome.net that will look at trends in the weather over many decades, and will focus on particular regions including Europe, north-western America and southern Africa.

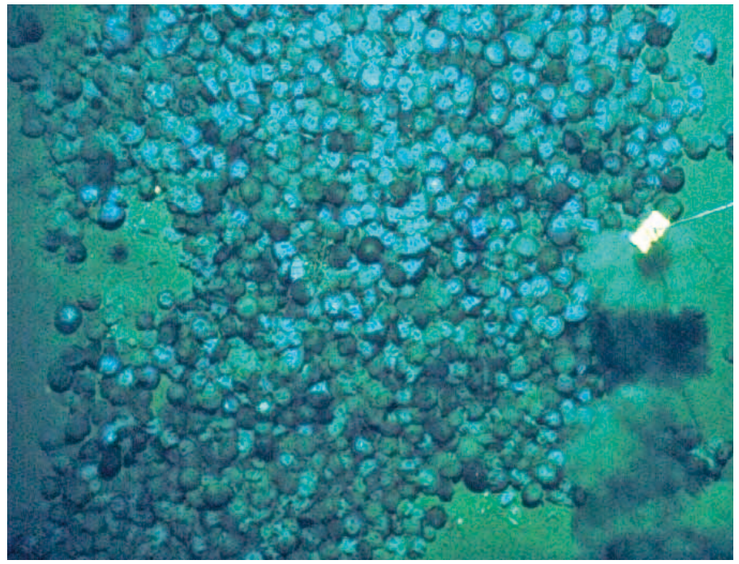
Climate models are only now starting to simulate the atmosphere at fine enough resolutions to allow this kind of regional simulation, and to let researchers link the results with other models to simulate the impact of weather, Pall explains.

One of his co-authors, Dr Peter Stott of the Met Office, is now looking at the possibility of running this kind of 'climate attribution' analysis constantly, like a weather forecast. This would give researchers a sense of how climate change is affecting the weather in near real time.

Eat your jellyfish!

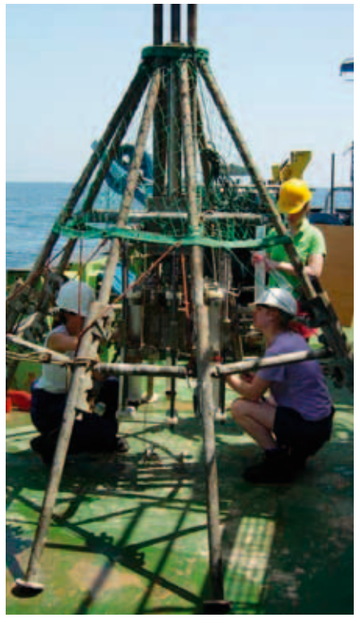
A large bloom of jellyfish in the Arabian Sea turns out to have provided food for micro-organisms on the deep-sea floor. Liz Fisher explains how this could help us understand how seabed communities adapt to changes in the supply of food and oxygen.

Reuters/Yo New



Above: Jellyfish carcasses on the sea floor at 1400m depth. The weight (seen to the right of the image) is dangled from the SHRIMP camera system which is positioned approx 2-3m above the sea surface.

In December 2002, scientists aboard the RRS *Charles Darwin* were surveying the geology and biology of the Arabian Sea off the coast of Oman. They were using a deep-towed video and camera imaging system called SHRIMP (Seafloor High Resolution IMaging Platform) to examine the sea floor. What they saw was a surprise – a large number of dead and decaying jellyfish (*Crambionella orsini*), some in deep-sea canyons, others rolling down the sloping seabed into the abyss. Jellyfish usually live at the surface, but carcasses were seen on the seabed as deep as 3.2km.



Scientists using a multicorer to take sediment samples. L-R Xana da Silva, Kate Larkin and Rachel Jeffreys.

Crambionella orsini is a native species of the Indian Ocean, living in surface waters but only very occasionally in large numbers. It is edible, and is exported from the Arabian Sea to China and Japan. Similar blooms have occurred elsewhere. For example, a mass deposition of jellyfish-like creatures called pyrosomes (*Pyrosoma atlanticum*) was discovered near the Ivory Coast in 2006. The patches of jellyfish found at the Oman Margin were several metres across, at least 7cm thick and covered about a fifth of the seabed. Other areas of sea floor were covered in a continuous layer of jelly 'slime'.

The scientists reported 'curious aligned striated patterns', which may have been formed by jellyfish dragging through the soft sediment surface as they tumbled down to the sea floor. They took images of the weight dangling below SHRIMP, dipping into the jelly slime, which let them gauge how deep the jelly detritus was. They estimated that this jelly detritus would provide ten times more food on the seabed than is normally produced each year by phytoplankton – the tiny algae that form the base of the marine food chain.

We're not sure why jellyfish blooms occur, but some people think they are becoming more common and that human activity may be partly to blame. Fish and jellyfish compete for the same prey. Fish also eat jellyfish, so overfishing would mean jellyfish have more food and fewer predators, so their numbers would rise. Global warming and pollution of coastal waters by fertilizers stimulate blooms of phytoplankton. Jellyfish prefer feeding on the smallest types of plankton, which tend to dominate these blooms, so they flourish. Living jellyfish were seen only in the well-oxygenated surface waters off Oman. It is possible that they were present in large numbers on the seabed because of the very low oxygen waters which occur in the Arabian Sea, forming a region known as the oxygen minimum zone (OMZ).

Oxygen minimum zone

This zone is caused by strong monsoon winds which blow from the north-east between December and March and from the south-west between June and September. This allows nutrient-rich water to well up into shallower regions from below, stimulating phytoplankton growth. Once the plankton die and sink, they decay, using up oxygen. This causes the OMZ to form, with very little dissolved oxygen (20 times less than in surface waters). The OMZ at the Oman continental margin (the region of the ocean between the deep sea and the shore) extends from 100m to around a kilometre deep. The dead carcasses presumably fall into the OMZ for a variety of reasons, including natural death. The OMZ would have slowed down their rate of decay as they sank through it, so more of the jelly detritus was deposited on the sea floor. However, jellyfish remains are not a long-term feature of the seabed because jellyfish blooms are rare and last only a few months at a time.

What effect does all this jellyfish detritus have on the creatures that live on the seafloor? This is where our work came in. We hypothesized that the clumps of rotting jellyfish might have caused areas of the seabed to become starved of oxygen and that this led to the rise of specialist bacteria. These microbes live on chemical energy from hydrogen sulphide (produced from the decay of organic matter, like jellyfish) rather than on the energy in sunlight, making their food by a process called chemosynthesis. Their chemical expertise lets them obtain energy with no need for oxygen. Other organisms can then feed on these specialised bacteria.

To test our hypothesis we decided to examine two similar environments – the Oman Margin and the Pakistan Margin. Both border the Arabian Sea and both have OMZs, but only the former had been affected by the jelly fall. In normal circumstances – that is, without a jelly fall – we would expect to find chemosynthesis occurring on both margins within the OMZs, but not above or below them. Would the jelly change this?

We examined foraminiferans from the Oman and Pakistan sediments. These are single-celled organisms which live in shells called tests. Depending on the species, the test may be made of organic material, sand grains and other particles cemented together, or secreted calcium carbonate. Radiating from the test's small opening are fine hair-like extensions of the cell known as reticulopodia, which the foraminiferans use to find and capture food. Some deep-sea species feed on the remains of phytoplankton which make their food using photosynthesis, but where there is little or no oxygen, they can also eat bacteria.

Photosynthesis or chemosynthesis?

We used a technique called stable isotope analysis to find out what the foraminiferans were eating. Carbon has two stable forms: Carbon-13 (heavy) and Carbon-12 (light). Stable isotope analysis lets us measure the ratios of these 'isotopes' by comparing them to the ratio of isotopes in a standard substance. If there is a higher proportion of the heavier isotope, the values are positive; if there is a lower proportion it is negative. The differences are so small that the values (called isotopic signatures) are measured in parts per thousand (‰). Chemosynthesis produces a different ratio from photosynthesis. For example, foraminiferans consuming food that was made by photosynthesis would give a value of -15 to -20‰, whereas those feeding on chemosynthetic food sources would have isotopic values outside this range.

We expected to find that foraminiferans living in the OMZ feed on both phytodetritus and chemosynthetic bacteria, whereas those outside it feed only on phytodetritus. This was the case off Pakistan where there had been no jelly fall. Yet off Oman, the results implied that foraminiferans were feeding on chemosynthetic bacteria even below the OMZ. This was exciting – it suggested that some species may be feeding on bacteria that live on the jelly detritus.

To confirm this, we also measured nitrogen stable isotopes. Nitrogen's stable isotopes are Nitrogen-15 (heavy) and Nitrogen-14 (light). If foraminiferans were eating phytodetritus, we would expect their signature to be 10-12‰. If they were eating chemosynthetic bacteria, the signature would be lower. Once again, in both places this was the case in the OMZ, confirming the bacteria were a food source. Yet at Oman, there were low nitrogen values below the OMZ, confirming our carbon results.

It certainly seems likely that the jelly has indirectly nourished certain foraminiferans at the Oman margin. If jellyfish do become more common in world oceans, then more of the seabed may be affected by their jelly remains. We don't know what this will mean for many deep-sea fauna, but it is likely that microbial communities will adapt readily to the new conditions. This could also have wider implications for how carbon moves through the ocean – it will greatly increase the amount of carbon delivered, via jelly detritus, to the seabed. ■

MORE INFORMATION

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FURTHER READING

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The streaked shearwater flies thousands of miles each year.

Robin Newlin/www.birdskorea.org

Shearwaters migrate thousands of miles each year in search of food, but short of taking to the air themselves, scientists have had no way of following their journey. Phil Trathan and colleagues explain how, thanks to some handy new kit, tracking shearwaters is no longer a flight of fancy.

Seasonal produce:

how shearwaters exploit the ocean's resources

The north-western Pacific is one of the most productive of our oceans, rich in life. It's a highly seasonal environment, so the amount of nutrients it contains, and where they are concentrated, varies over the year. This means the amount of food available to marine organisms and the animals that depend on them changes too, and food has a powerful influence on the distribution of many marine creatures, including seabirds.

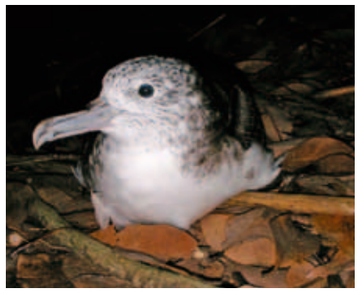
The streaked shearwater, *Calonectris leucomelas*, flies many thousands of miles each year in response to this seasonality. Shearwaters are pelagic birds, in other words they spend the majority of their time out at sea, coming to land to breed around the coasts of east and south-eastern Asia.

After breeding, shearwaters migrate south towards the equator, to spend the winter in warmer tropical regions. But though they have been seen at various different wintering grounds, until now there has been no way of knowing where individual birds have come from, nor what influences their choice of migratory route.

Working with Akinori Takahashi and Takashi Yamamoto from the National Institute of Polar Research, we spent four years investigating the links between the region's seasonality and the birds' behaviour – how they choose their wintering grounds and migratory routes, and find food along the way. Our breakthrough came from the British Antarctic Survey's (BAS) development of some micro-electronic equipment which means that, for the first time, we have been able to track the birds' epic journeys.

Our information came from global location sensors which we attached to the legs of breeding birds at two shearwater colonies off the east coast of Japan: Sangan Island and Mikura Island. These clever devices weigh just 4.5g and measure 25 x 18 x 7mm but BAS has packed a lot in that small space. The sensors have a real-time clock and measure light levels, so that we can estimate longitude and latitude to work out the bird's location. They also have a saltwater activity sensor which indicates whether conditions are wet or dry – in other words whether the birds are flying (or on land) or are on the sea surface. The light sensors enable us to produce two positions for each bird each day while the activity sensor generates a wet/dry record every ten minutes; together the results effectively allowed us to produce a map of the route each bird had taken, showing when and where it had landed on the sea to feed or rest.

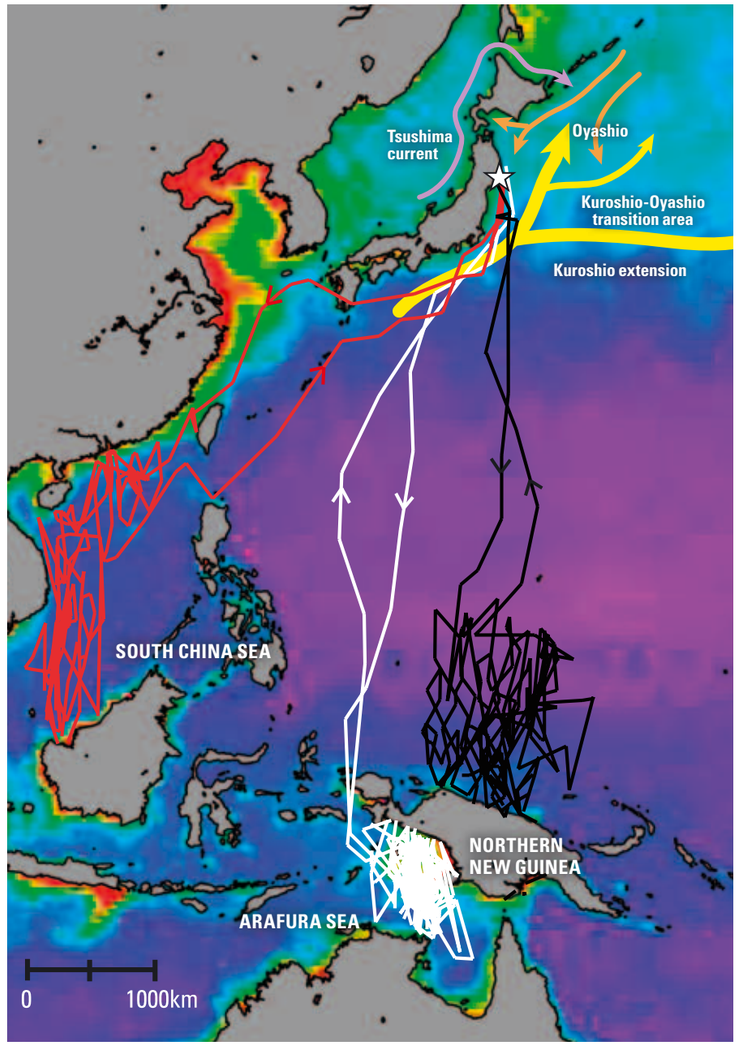
Our first discovery was that streaked shearwaters migrated from the seas around Japan to three main wintering areas in the tropics. Most of our birds wintered off northern New Guinea, but some went to the South China Sea, and others as far as the Arafura Sea, between New Guinea and Australia: respectively 4000km, 3500km and 5400km from the breeding colony. These different wintering sites may be traditional areas, but it remains to be seen whether individuals always use the same site in subsequent years, and if so what causes birds to select particular sites.



The area to the north of New Guinea is an area of low primary productivity (in the oceans primary producers are generally phytoplankton which form the base of the food chain), but the birds still seemed to like it there. The trackers revealed that, around dawn and dusk, the shearwaters flew for longer periods and landed on the water more frequently. What could this mean? This pattern is similar to that of other tropical seabirds that we know feed in association with subsurface predators such as tuna. We think the birds may benefit from easy access to prey driven to the ocean surface by the predator, or from scraps of fish it leaves behind. So it looks like our streaked shearwaters also have the knack of using these big fish to find their own food during the wintering period. Shearwaters are certainly efficient gliders, so they could cover large areas without using too much energy: a real issue in ecosystems where productivity is low.

We also know that the moon affects the behaviour of some marine animals, particularly zooplankton and their predators. But we don't know very much about how seabirds and marine mammals respond to the lunar cycle, mainly because it has been so difficult to record their behaviour during long periods at sea. Our GLS loggers proved sufficiently sensitive for us to record the birds' behaviour at sea throughout the winter, including how this varied with the lunar phase. Our results showed that streaked shearwaters do change their behaviour in response to the phase of the moon: birds flew for longer and landed on water more frequently on nights with a full moon than when there was a new moon. So it looks like the at-sea behaviour of these pelagic seabirds is also closely associated with the lunar cycle.

Once we knew more about the shearwaters' winter life, we turned our attention to how they lived for the rest of the year. It turned out that the birds stayed in Japanese coastal waters and their main foraging areas moved north as the breeding season progressed. The sea off the east coast of Japan is dominated by the Kuroshio and Oyashio currents, which cause sea-surface temperatures to increase rapidly from spring to summer. Shearwaters from Sangan Island focused their foraging activities along the coastal areas where the two ocean currents meet, while birds from Mikura Island moved northwards along the Kuroshio current, probably following the migration of warm-water pelagic fish – including their main prey the Japanese anchovy *Engraulis japonicas*.



The migratory routes of the shearwater where the black line indicates the route to northern New Guinea, the white line to the Arafura Sea and the red line to the South China Sea. The star indicates the breeding colony. Orange and yellow arrowed lines indicate the direction of the ocean currents.

We also saw differences in the behaviour of male and female birds. For example, during the pre-laying period, males foraged much closer to the colony than females; they spent less time at sea and returned to the colony more often. But once the eggs were incubating there were no obvious differences in foraging areas between the sexes.

So the shearwaters travel great distances as the seasons change, but once the breeding season kicks off it looks like the location of their colony, and the different roles played by the sexes, become the primary influences on their foraging.

Thanks to the detailed information the tiny data loggers recorded, we've been able to join up many of the pieces of the streaked shearwater puzzle. We now know a huge amount more about their lives on land and out at sea, and why they behave the way they do. ■

MORE INFORMATION
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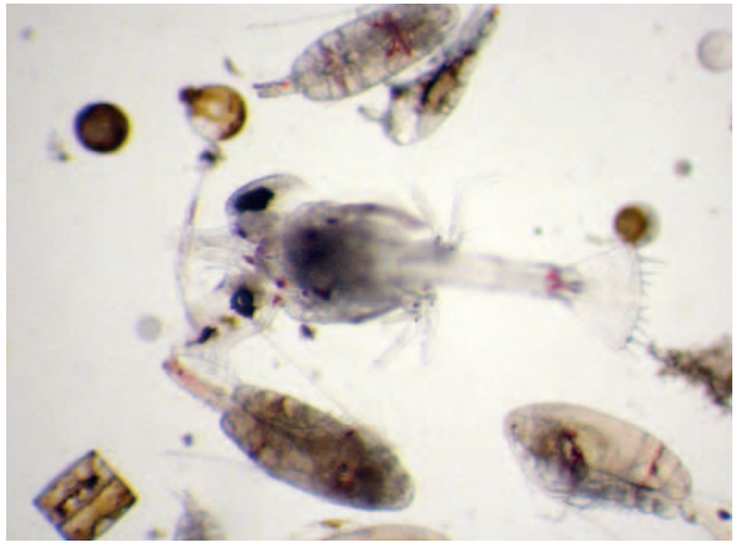
Going Global
the next 80 years

The Continuous Plankton Recorder (CPR) Survey celebrates its 80th anniversary this year. Peter Burkill outlines what makes the survey unique, describes some of its recent discoveries, and sets out what he hopes will be achieved next.

The CPR being launched from the back of a ferry.



Plankton community showing summer phytoplankton and zooplankton species collected by the CPR from the English Channel.

The CPR Survey is managed by the Sir Alister Hardy Foundation for Ocean Science (SAHFOS), an institution recognised as a leading authority on plankton biodiversity. SAHFOS is located in Plymouth, UK, a city with a long history of marine biological research.

What is plankton biodiversity? And why does it matter? Plankton are microscopic organisms found in a myriad of diverse forms in all waters. Pick up a cup full of natural seawater and you will be holding thousands or even millions of individual plankton organisms. You would also be holding hundreds or thousands of different forms that can be aggregated into functional groups.

Both the abundance and the diversity are important because each functional group plays a different role in the natural processes of life. The phytoplankton regulate our climate by absorbing carbon dioxide from the atmosphere in sunlit surface waters, where they photosynthesise. This activity also produces oxygen – in fact, half the oxygen we breathe comes from plankton. The destiny of phytoplankton in the food web is to be grazed by zooplankton, which in turn are eaten by fish. Plankton are the lifeblood of all aquatic systems; without them, life on our planet would be impossible in its present form.

The CPR Survey owes its existence to one man: Alister Hardy. Hardy, who became Linacre Professor of Zoology at the University of Oxford in 1947, was a naturalist who combined meticulous observation with enormous patience and considerable inventiveness to address matters of practical importance. From 1925 to 1927, he worked on whale conservation in the Antarctic and realised that understanding plankton (the main food of whales) was crucial to this. To do this during his time at sea, he developed the Continuous Plankton Recorder to let him determine the distribution and abundance of plankton.

From 1931, Alister Hardy used the CPR to help fishermen decide where to let out their nets to catch fish. In the North Sea, despite the high level of fish production, fishermen were puzzled about why they sometimes caught few fish, while on other occasions their nets bulged with their catches. Hardy's project was interrupted by the Second World War, but when the war ended, fish-finding electronics were developed and Hardy set off on a new tack – understanding how plankton are distributed across whole marine basins. Initially this was the North Sea, but in 1959, the first trans-Atlantic tow was carried out to Newfoundland in Canada.

The Continuous Plankton Recorder

The CPR is an ingenious device designed to be towed by a merchant ship; it produces a continuous record of the plankton present in the water. The recorder is a metre long and made of stainless steel. It is towed at a depth of about 10 metres and operates successfully at speeds of up to 25 knots. Its robust design means it can be deployed in rough seas – successful tows have been continued through sea states of up to wind force 11 on the Beaufort scale, classified as a 'violent storm'.

Water enters the recorder through a hole at the front, and the plankton are caught on a strip of silk that is wound continuously by an impeller. A second layer of silk sandwiches the plankton as it is wound into a storage tank, where the plankton are preserved with formalin. Silks are held on cassettes that are changed every 800km. At the end of the tow, the CPR is sent back to Plymouth, where scientists identify the plankton that has been captured and analyse its abundance distribution.

The survey involves regular monthly tows using merchant navy vessels along some 30 routes covering large expanses of the North Atlantic and North Sea. The results underpin research into climate, pollution and fisheries in the UK and other European countries, as well as Canada and the USA. Data obtained is made available for scientists and a wide variety of organisations including the United Nations Intergovernmental Panel on Climate Change.

The survey area has gradually expanded. In 2000, the first tow in the Pacific was carried out, stretching between Vancouver, Canada, and Hokkaido in Japan. Another set of new tows started in 2005 in the Southern Ocean, using the British Antarctic Survey vessel RRS *James Clark Ross*.

In 2009 we expanded the Atlantic Survey into Arctic waters, to reflect the huge northerly movement that has been recorded in the plankton of the eastern Atlantic – plankton communities are now found some 1000km further north than they were five decades ago. This is particularly relevant to fish such as cod and seabirds like kittiwakes that depend on plankton for their survival.

Map of the routes which make up the North Atlantic Ocean CPR Survey.

Plankton communities

An early discovery of the CPR Survey was the presence of different communities of plankton in the North Atlantic. Just as there are distinct communities of terrestrial plants in different areas, so there are marine phytoplankton communities. For example, the communities of the Pacific and Atlantic differ. In 1999, a small phytoplankton called *Neodenticula seminae* was found in the North Atlantic.

This was noteworthy for two reasons: according to the geological record, it was last found in the Atlantic 800,000 years ago. Today, it is common in the North Pacific. We think this species has been transferred via the Arctic Ocean where the ice has retreated to allow passage of viable organisms. Today it is flourishing in the Atlantic. Whether it will outcompete the native plankton remains to be seen.

The large numbers and wide diversity of plankton make them excellent indicators of how the ocean environment is changing. For example, a recent discovery is that a water temperature of 10°C represents a tipping point between the Arctic and sub-Arctic plankton communities in the northern Atlantic.

What is unusual is that the phytoplankton, zooplankton and fish of these communities vary together, showing that this temperature represents a natural boundary across the whole North Atlantic. This simple but spectacular discovery means we will be able to forecast the locations of fisheries in the North Atlantic over the coming decades.

The more we learn about how plankton are distributed in the oceans, the more we realise the need for a broad geographical perspective. The ideal would be a global perspective. Over the last ten years, SAHFOS has helped Australia, New Zealand and the USA to start up local surveys. This year we are helping South Africa to start one of its own. Slowly but surely the beginning of a global perspective is evolving. In September 2011, as part of our 80th anniversary celebrations, we will host an international workshop with scientists from some 12 countries and several international organisations.

We plan to form a Global Alliance of CPR Surveys (GACS) with partners who will work together to achieve this global perspective on the oceans' plankton populations. We will then know more about changes in plankton biodiversity and how this affects the sustainability of our planet. Perhaps in 80 years' time, GACS will be celebrating its success in understanding the world's plankton diversity just as we are doing for the North Atlantic this year. ■

MORE INFORMATION

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